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FOR: ELECTRIC POWER STEERING APPARATUS

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TITLE OF THE INVENTION

ELECTRIC POWER STEERING APPARATUS

BACKGROUND OF THE INVENTION

5 1.Field of the Invention

The present invention relates to an electric power steering apparatus having a steering system capable of flexibly setting a relationship between a steering angle of a steering wheel and a wheel angle of a tire.

10 2.Description of the Related Art

Conventionally, as is known in the related art, a steer-by-wire (SBW) system is the system in which a steering shaft as a drive shaft coupled to a steering wheel is mechanically separated from a driven mechanism setting a proceeding direction of tires independently. This system allows wider range of

15 control options compared with a conventional steering system in which the steering wheel and the tires are coupled through a mechanical linkage. As an example, Japanese Unexamined Patent Application Publication No. 2000-128002 discloses a

20 steer-by-wire control device in which a steering reaction force is determined based on the steering drive condition and the steering driven position. In the art disclosed in it, the steering reaction force acting on the steering shaft is determined by mainly using only a steering angle as the steering

25 drive condition being input information.

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However, in the above art, the ste ring reaction force is determined by considering only the condition in which the steering wheel is steered, and there is no consideration with respect to an appropriate value of the steering reaction force

5   in a region of "on-center feeling", which is the basis of the drivability. Here, this "on-center feeling" is due to a torque which is exerted on the steering wheel in case of slightly turning a vehicle. In this on-center region, if the torque to assist the steering of the steering wheel is too large, the driver

10   cannot feel the center of the steering wheel (that is, straightly driving condition). As a result, there happens the problem that drivability is decreased. On the other hand, in this region, if this assist torque is too small, the drivability of straightly driving is increased, but there happens another problem that

15   the driver's burden to turn the vehicle is increased.

Further, on-center feeling relates to a ratio (angle gain) of the wheel angle of the tire against the steering angle of the steering wheel. When this angle gain is small, the directional change of the tire becomes insensitive against

20   operation of the steering wheel. Thus, while it becomes easy for the driver to keep the vehicle in a direction of straight driving, there happens the above mentioned problem on the driver's burden, because to turn the vehicle requires the driver wider range steering of the steering wheel. On th other hand,

25   when the angle gain is large, since the directional change of

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the tire is sensitive against the operation, this results in an inconvenience in reverse to that occurring when the angle gain is small.

5   SUMMARY OF THE INVENTION

It is object of present invention to improve steering feeling and steerability by adjusting a torque gain and an angle gain in the electric power steering apparatus.

A first invention provides an electric power steering
10 apparatus having a steering system capable of flexibly setting a relationship between a steering angle of a steering wheel and a wheel angle of a tire. A first motor controls a steering reaction force exerted on the steering wheel. An on-center region determination section determines whether the steering
15 wheel is in a position of an on-center region. A tire reaction force torque detection section detects a tire reaction force torque transferred from the tire. A control section calculates a steering torque based on the tire reaction force torque and a torque gain. This torque is detected by the tire reaction
20 force torque detection section. And the control section controls the first motor to exert the steering reaction force corresponding to the above calculated steering torque on the steering wheel. This control section also sets the torque gain in case of determining that the steering wheel is in the position
25 of the on-center region larger than the torque gain in case

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of determining that the steering wheel is not in th position
of the on-center region.

A second invention provides an electric power steering
apparatus having a steering system capable of flexibly setting
a relationship between a steering angle of a steering wheel
and a wheel angle of a tire. In order to improve an on-center
feeling, this novel apparatus has a first motor, a second motor,
a steering angle detection section, an on-center region
determination section, a tire reaction force torque detection
section and a control section. The first motor controls a
steering reaction force exerted on the steering wheel. The
second motor for controls the wheel angle of the tire. The
steering angle detection section detects the steering angle
of the steering wheel. The on-center region determination
section determines whether the steering wheel is in a position
of the on-center region. The tire reaction force torque
detection section detects a tire reaction force torque which
is transferred from the tire. The control section calculates
a steering torque based on the tire reaction force torque and
a torque gain. This torque is detected by the tire reaction
force torque detection section. The control section controls
the first motor to exert the steering reaction force
corresponding to the calculated steering torque on the steering
wheel. This section also calculates the wheel angle based on
the ste ring angle detected by the steering angle detection

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section and an angle gain. And this controls the second motor so that the wheel angle of the tire corresponds to the calculated wheel angle. Further, the control section sets the torque gain in case of determining that the steering wheel is in the position

5 of the on-center region larger than the torque gain in case of determining that the steering wheel is not in the position of the on-center region. And this section also sets the angle gain in case of determining that the steering wheel is in the position of the on-center region smaller than the angle gain

10 in case of determining that the steering wheel is not in the position of the on-center region.

A third invention provides an electric power steering apparatus having a steering system capable of flexibly setting a relationship between a steering angle of a steering wheel

15 and a wheel angle of a tire. In order to improve an ability of turning (swinging), this apparatus has a first motor, a second motor, a steering wheel angle detection section, an on-center region determination section, a tire reaction force torque detection section and a control section. The first motor

20 controls a steering reaction force which is exerted on the steering wheel. The second motor controls the wheel angle of the tire. The steering wheel angle detection section detects the steering angle of the steering wheel. The on-center region determination section determines whether the steering wheel

25 is in a position of an on-center region. The tire reaction

force torque detection section detects a tire reaction force torque which is transferred from the tire. The control section calculates a steering torque based on the tire reaction force torque detected by the tire reaction force torque detection section and a torque gain. This section controls the first motor to exert the steering reaction force corresponding to the calculated steering torque on the steering wheel. The section also calculates the wheel angle based on the steering angle detected by the steering angle detection section and an angle gain. Then the section controls the second motor so that the wheel angle of the tire corresponds to the calculated wheel angle. Further, the control section sets the torque gain in case of determining that the steering wheel is in the position of the on-center region smaller than the torque gain in case of determining that the steering wheel is not in the position of the on-center region. And this control section also sets the angle gain in case of determining that the steering wheel is in the position of the on-center region larger than the angle gain in case of determining that the steering wheel is not in the position of the on-center region.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram showing the entire structure of an electric power ste ring apparatus;

FIG. 2 is a control block diagram;

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FIG. 3 is a diagram showing the relationship between a tire reaction force torque and a steering torque;

FIG. 4 is a diagram showing the relationship between a steering angle and a steering torque;

5 FIG. 5 is a diagram demonstrating a case where an angle gain of a second embodiment is a variable;

FIG. 6 is a diagram demonstrating a stability determination map in a fourth embodiment;

FIG. 7 is a diagram showing the relationship between a 10 steering angle and a steering torque in a sixth embodiment;

FIG. 8 is a diagram demonstrating upper and lower limit values of an angle gain in a seventh embodiment;

FIG. 9 is a diagram demonstrating upper and lower limit values of a torque gain in a seventh embodiment; and

15 FIG. 10 is a diagram showing the entire structure of a wheel angle superimpose system.

DESCRIPTION OF PREFERRED EMBODIMENTS

(First Embodiment)

20 FIG. 1 is a diagram showing the entire structure of an electric power steering apparatus. This structure diagram shows a steer-by-wire system including a first motor 103 controlling a steering reaction force which is exerted on a steering wheel 10, and a second motor 104 controlling a wheel 25 angle (actual set angle) of a tire 20. This system mainly

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includes two functions. The first is a function that the first motor 103 generates a control torque corresponding to a tire reaction force, which is transferred from the tire 20, and it exerts this control torque as a steering torque on the steering

5   wheel 10. The second is a function that the second motor 104 generates a control torque corresponding to the steering angle of the steering wheel 10, and controls the wheel angle of the tire 20.

FIG. 2 is a control block diagram of the steer-by-wire

10   system. Here, this figure shows a relationship between input and output blocks, which is discussed not only in first embodiment, but also in second embodiment or later, and thus, it should be noted that it is referred in every embodiment. A tire reaction force torque detection section 102 detects a

15   tire reaction force torque Tf which is transferred from the tire 20. A steering angle detection section 105 detects a steering angle θh of the steering wheel 10, and a wheel angle detection section 106 detects a wheel angle θf of the tire 20. A vehicle speed detection section 111 detects a vehicle speed

20   υ, and a steering speed detection section 112 detects a steering speed HS of the steering wheel 10, that is, the steering amount per a unit time. Further, as shown in FIG. 1 to improve steering feeling and driving stability, there provides a vehicle condition amount detection section 108. This detection section

25   108 detects various types of information indicating the driving

condition of the vehicle (vehicle condition amount) such as a yaw rate, a lateral acceleration (acceleration of the vehicle in the lateral direction), a skid angle, or a road surface friction coefficient μ. Herein, it is not necessary that the

5   vehicle condition amounts include all of them. A current flowing to the motors 103 and 104 and a voltage between motor terminals are detected for controlling the respective motors, these are not shown in this figure.

Herein, other than being directly detected by the tire

10   reaction force detection section 102, the tire reaction force torque Tf may be estimated by using outputs such as a driving current or a rotation acceleration of the second motor 104 controlling the wheel angle (the same is applicable to the embodiments which are to be described later). Here, assuming

15   that a torque constant of the motor 104 is Kt2, a current of the motor 104 is If, an inertia of the motor 104 is J2, and an acceleration of the motor 104 is $d\omega2/dt$, the tire reaction force torque Tf can be calculated by the following equation.
[Equation 1]

20       $$Tf = If \cdot Kt2 - J2 \cdot d\omega2/dt$$

The control section 107 is a computer (steering control controller) mainly comprising CPU, ROM, RAM, an input/output interface, and the like. Here, other than a map for setting a torque gain $\alpha22$ which will be described later, the ROM stores

25   a stability determination map (described in fourth embodiment),

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upper and lower limit values of α22 and α11 (described in seventh embodiment), and the like. Interpreting functionally the control section 107, this section 107 includes an on-center region determination section 120, a steering torque control section 121, a wheel angle control section 122, and motor current decision sections 123a and 123b. The control section 107 performs an angle control of the tires and a torque control of the steering wheel in such a manner as to establish the following equation. Here, θh is a steering angle of the steering wheel 10, θf is a wheel angle of the tire 20, Tf is a tire reaction force torque, Th is a steering torque, α11 is an angle gain, and α22 is a torque gain.

[Equation 2]

$$\theta f = \alpha 11 \cdot \theta h$$

$$Th = \alpha 22 \cdot Tf$$

The on-center region determination section 120 makes a determination about an "on-center region", which is important for performing the angle control and the torque control in the present embodiment. Here, the "on-center region" is a region in which the position of the steering wheel 10 is regarded as being close to neutral. In the present embodiment, the determination about the on-center region is made mainly by using information about the steering reaction force corresponding to the calculated steering torque. To be specific, turning to one direction (for example, turning-right) and turning to

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the other direction (for example, turning-left) of the steering

wheel 10 are estimated based on the steering torque Th and the

steering speed. It is determined as being on-center region,

in case of ±2Nm or lower (that is, |Th|=2 or |Th|<2) on turning

5   to one direction, and in case of 0 Nm on turning to the other

direction. However, it should be noted that the concrete value

of the steering torque Th differs depending on which vehicle,

and thus a threshold value (±2Nm) providing a determination

criterion   for   the   on-center   region   is   determined   in

10   consideration of the specifications of the vehicle. Surely,

in a system including a sensor for detecting the steering torque,

the above-described on-center region may be determined by using

the steering torque detected by the sensor. In the embodiments

described below, the to-be-used value of the steering torque

15   may be either the calculated value or the detected value.

        The wheel angle control section 122 calculates the wheel

angle θf by multiplying the steering angle θh detected by the

detection section 105 by the angle gain α11 (fixed value in

the present embodiment). The second motor current decision

20   section 123b decides a target value of the current for driving

the second motor 104 in response to the wheel angle θf calculated

by the control section 122, and it is output to the second motor

current control section 130b. This allows such feedback control

that the actual current of the second motor 104 equals to the

25   target value, whereby the wheel angle of the tire 20 is controlled

to be θf or so.

In the present embodiment, the angle gain α11 is a fixed value (constant value). The value of the angle gain α11 is a ratio between the steering angle θh and the wheel angle θf, and corresponds to reciprocal of the one called overall steering gear ratio. With respect to a general vehicle, the angle gain α11 is often set to be about 1/15 to 1/20. However, to realize the function of the steering system called a variable gear system, it may be set to be 1/10 at low vehicle speed, and 1/30 at high vehicle speed, for example.

On the other hand, the steering torque control section 121 calculates the steering torque Th by multiplying the tire reaction force torque Tf detected by the detection section 102 by the torque gain α22. The torque gain α22 is variable unlike the angle gain α11 described above. The first motor current decision section 123a decides a target value of the current for driving the first motor 103 in response to the steering torque Th calculated by the control section 121, and it is output to the first motor current control section 130a. This allows such feedback control that the actual current of the first motor 103 equals to the target value, whereby the first motor 103 exerts a predetermined torque derived by multiplying the current value by both the torque constant and the gear ratio (between the motor and the steering shaft). As a result, the steering torque at the time when the driver operates the steering wheel

10 is controlled to be Tf or so.

Here, as shown in FIG. 3, the torque gain α22 corresponding to the inclination of a straight line in a coordinate system of the tire reaction force torque Tf and the steering torque

5　Th is set to be variable depending on the driving condition. In detail, when the determination section 120 determines that the steering wheel 10 is not in the position of on-center region, a torque gain predetermined value corresponding to the inclination of the thick actual line in the figure is used as

10　the torque gain α22. On the other hand, when the steering wheel 10 is determined as positioning in the on-center region, used as the torque gain α22 is a value larger than the torque gain predetermined value. Moreover, in this case, the faster the vehicle speed v, the larger the value of the torque gain α22

15　will be. As an example, the torque gain predetermined value may be set to be a half of the torque gain of manual steering. This value is a torque gain value that indicates the ratio of the steering torque against the tire reaction force with respect to the general power steering system. This value is also the

20　one introduced in the document authored by kenneth D. Norman (Object Evaluation of On-Center Handling Performance, SAE paper 840069, 1984). Further, by making this torque gain predetermined value equal to or larger than the torque gain with respect to manual steering, the tire reaction force larger

25　than that of the manual steering is transferred to the driver.

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Accordingly, the on-center feeling of the steering wheel 10 can be further improved.

FIG. 4 is a diagram showing a relationship between the steering angle θh and the steering torque Th. As shown in this figure, in the present embodiment aiming for improvement of the on-center feeling, an inclination in the on-center region (hatched region) becomes larger compared with the characteristics of manual steering and the characteristics of general power steering. Therefore, according to the present embodiment, derived is the on-center feeling equal to or larger than manual steering, and the like.

As such, according to the present embodiment, the on-center feeling is increased, thereby enabling to improve operation feeling. Generally, to drive the vehicle in the on-center region, the steering torque Th of the steering wheel 10 being moderate amount will help the driver to drive with better steering feeling. As in the present embodiment, in the steering system capable of flexibly setting the relationship between the steering angle θh and the wheel angle θf, the steering torque Th to be transferred to the steering wheel 10 can be independently determined irrespective of the wheel angle θf. Utilizing such characteristics, when the steering wheel 10 is in the position of on-center region (i.e., close to the neutral position), the torque gain $\alpha 22$ is set larger than one when not in the region. As a result, th steering torque in the on-center

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region is increased by the increase of the torque gain α22, thereby enabling to improve the on-center feeling.

(Second Embodiment)

In the first embodiment described in the foregoing, the angle gain α11 is a fixed value. In the present embodiment, it is assumed to be a variable. Here, the entire system structure, and the basic parts relating to control over the wheel angle and the steering torque are similar to the first embodiment (especially FIGS. 1 and 2), and thus not described again (the same is applicable to the embodiments which will be described later).

For example, when an obstacle object in front of the vehicle is detected by a monitor sensor such as a stereo camera, a laser radar, or an infrared radar, it may be necessary to avoid it urgently. In such an urgent avoidance, the wheel angle control section 122 sets the value of the angle gain α11 larger than a standard value, as shown in FIG. 5. As an example, in a case of a vehicle with the standard value of the angle gain α11 being 1/15, the angle gain α11 is set to be 1/10 at the time of detecting the object. In this manner, on detecting the object, the vehicle becomes easier to make a turn about 1.5 times than when driving normally. Accordingly, the steerability (ability to avoid objects) is improved. Further, on detecting the object, it is preferable for the steering torque control s ction 121 to also set the value of the torque gain α22 smaller than when

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driving normally. This makes the steering torque Th less as well, the steering wheel 10 can be operated more swiftly (improvement of swinging).

Moreover, in case of driving on expressways and the like,

5   it is determined whether to continue to drive straightly by detecting process associated with a navigation system, as shown in FIG. 5, the wheel angle control section 122 may set a value of the angle gain $\alpha 11$ smaller than its standard value. By setting the angle gain $\alpha 11$ smaller when straight driving is expected

10   for a while, the response of the vehicle becomes insensitive against the operation of the steering wheel 10. Accordingly, it is easy for driver to operate the steering wheel 10 in case of driving straightly. Similarly, at the time, the value of the torque gain $\alpha 22$ may be set larger. In such a manner, the

15   steering torque Th becomes more, and the on-center feeling of the steering wheel 10 is validly transferred to the driver, thereby reducing a burden of steering.

As such, according to the present embodiment, by setting the angle gain $\alpha 11$ to be variable in response to the driving

20   condition, the operability can be improved. Further, compared with the first embodiment in which the angle gain $\alpha 11$ is a fixed value, the vehicle behavior responding to the wheel steering can be flexibly set in response to the driving condition, or the driver's preferences. As a result, this improv s the

25   fl xibility in terms of a setting of the wheel angle (actual

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wheel angle of tire).

(Third Embodiment)

In the above embodiments, determination about the on-center region is made based on the steering torque Th. In the present embodiment, determination is made based on the lateral acceleration. In detail, the on-center region determination section 120 determines that, if the lateral acceleration is a predetermined threshold value or smaller (e.g.,±0.1G), then the steering wheel 10 positions in the on-center region. This threshold value is varied depending on which vehicle, and thus should be determined in consideration of the specification value of the vehicle. Detecting the lateral acceleration is enabled by employing an acceleration sensor on the vehicle. Alternatively, it is possible to derive through communication means such as CAN from other vehicle-mounting type system. In addition, other then the method carried out based on the lateral acceleration, the determination about the on-center region can be carried out based on the various vehicle condition amounts such as the tire reaction force and the steering angle. Note here that, these matters are applicable also to the embodiments described later.

(Fourth Embodiment)

In the present embodiment, using a stability determination map defining the relationship between the yaw rate and the skid angle of the vehicle, the driving stability

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of the vehicle is determined based on the distance between a coordinate point, which identifies from a skid angle and a yaw rate, and an origin. According to the determination result, the angle gain $\alpha11$ and the torque gain $\alpha22$ are changed. For

5   this purpose, to the structure of the above embodiments, a yaw rate sensor and a skid angle sensor are newly added to detect the vehicle condition amount such as the yaw rate and the skid angle. To improve the driving stability of the vehicle, the control section 107 changes the angle gain $\alpha11$ and the torque

10 gain $\alpha22$ to be variable in response to the vehicle condition amount. Here, the condition amount may be captured from other vehicle-mounting type system through CAN.

FIG. 6 is a diagram for demonstrating the stability determination map in the present embodiment. The method for

15 determining the vehicle driving stability is introduced in the document authored by Kin, et al., "Improvement of vehicle's stability and steerability by skid control" (Honda R&D Technical Review, Vol. 13 No1 2001). In the present embodiment, for example, stability determination may be made with βmax being

20 5deg, and γmax being 30deg/sec. In this figure, the distance between the coordinate point (skid angle, yaw rate) and the origin indicates the vehicle stability. When the coordinate point is located in the hatched region, it is determined as being stable driving, and when located outside the region, it

25 is determined as being unstable driving.

On determining as being stable driving, as a normal driving mode, based on the above-described embodiments, the angle gain $\alpha 11$ and the torque gain $\alpha 22$ are set to be normal values. These normal values are set based on the above-described embodiments.

5   On the other hand, on determining as being unstable driving, the torque gain $\alpha 22$ is set larger than its normal value. In this manner, the tire reaction force is transferred larger to the driver, and thus the driver can correctly sense the road condition from the steering wheel 10. Similarly, on determining

10   as unstable driving, the angle gain $\alpha 11$ is set smaller than its normal value. In this manner, the vehicle behavior with respect to the wheel steering becomes insensitive. Steering the wheel in the region where vehicle driving is not stable is difficult for the general drivers. Erroneous driving

15   operation may make the vehicle unstable. Thus, when the vehicle is not stable, the angle gain $\alpha 11$ is made smaller to prevent the driver's erroneous driving operation, and the torque gain $\alpha 22$ is made larger to provide road surface information needed for stabilizing the vehicle to the driver.

20   As such, according to the present embodiment, when the vehicle driving condition becomes unstable, the vehicle behavior becomes insensitive, and the steering torque becomes sensitive. Accordingly, the vehicle stability can be successfully increased.

25   Additionally, in the present embodiment, the stability

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is determined in binary (stable driving, unstable driving),
and the gains $\alpha 11$ and $\alpha 22$ are set in binary. However, the gains
$\alpha 11$ and $\alpha 22$ may be consecutively set. For example, in the
above-described stability determination map, the distance
between the coordinate point which is identified by both the
skid angle and the yaw rate, and the origin is calculated, then
the gains $\alpha 11$ and $\alpha 22$ are linearly changed in response to this
calculated distance. In this case, as the distance becomes
longer (as the driving stability becomes lower), the value of
the angle gain $\alpha 11$ is consecutively decreased, and the value
of the torque gain $\alpha 22$ is consecutively increased.
(Fifth Embodiment)

In the present embodiment, in order to improve the driving
stability of the vehicle through estimation of the road surface
friction condition, based on the estimation result, the angle
gain $\alpha 11$ and the torque gain $\alpha 22$ are controlled to be variable.
In detail, based on the lateral movement equation of the vehicle
using adaptive control theory, the control section 107
calculates/estimates cornering power of the front and rear
wheels of the vehicle. Then, the control section 107 calculates
an estimation value of the road surface friction coefficient
corresponding to the road surface condition in response to the
cornering power of the front and rear wheels. Then, when this
estimation value is a predetermined threshold value or larger
(e.g., $\mu = 0.7$), det rmination is made as a high μ road. When

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the value is smaller than that, determination is made as a low

μ road. Here, such an estimation technique is described in

detail in Japanese Unexamined Patent Application Publication

No. 11-101732, and refer thereto if needed.

5   When the road surface is determined as being the high

μ road, the angle gain α11 and the torque gain α22 are set to

be normal in value. These normal values are based on the

above-described embodiments. On the other hand, when the road

surface is determined as being the low μ road, the angle gain

10   α11 is set smaller than its normal value, and the torque gain

α22 is set larger than its normal value. Therefore, even when

condition of the road is slippery, it becomes able to ensure

the stable driving of the vehicle.

          Additionally, in the present embodiment, the condition

15   of the road surface μ is determined in binary (stable driving,

unstable driving), and the gains α11 and α22 are set in binary.

However, these gains α11 and α22 may be consecutively set. In

this case, as road surface μ becomes lower in condition (that

is, as the road surface becomes slippery in condition), a value

20   of the angle gain α11 is consecutively decreased, and a value

of the torque gain α22 is consecutively increased.

(Sixth Embodiment)

          FIG. 7 is a diagram showing the relationship between the

steering angle θh and the steering torque Th in the present

25   embodiment, and it shows a method for determining the torque

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gain α22 with the angle gain α11 made smaller. In the above

embodiments, as shown in the above equation 2, the angle gain

α11 and the torque gain α22 are each independently calculated.

In the present embodiment, on the other hand, these are

5 calculated while interrelated to each other in accordance with

the following equation. Herein, K is an arbitrary constant.

[Equation 3]

$$\theta f = \alpha 11 \cdot \theta h$$

$$Th = \alpha 22 \cdot Tf$$

10 $$Tf = K \cdot \theta f$$

$$Th/\theta h = K \cdot \alpha 11 \cdot \alpha 22$$

As described in the foregoing, with $Th/\theta h$ being a constant

value ($K \cdot \alpha 11 \cdot \alpha 22$), $\alpha 11 \cdot \alpha 22$ becomes also a constant value.

This means that the product of the angle gain α11 and the torque

15 gain α22 is a constant value. By making $Th/\theta h$ a constant value,

determining the torque gain α22 uniquely determines the angle

gain α11. As such, by making the product of the angle gain

α11 and the torque gain α22 a constant value, the operation

process can be decreased in load. Here, the technique according

20 to the present embodiment is applicable to any of the above

embodiments.

(Seventh Embodiment)

The present embodiment is characterized in providing the

angle gain α11 and the torque gain α22 with an upper limit value

25 and a lower limit value, respectively. FIG. 8 is a diagram

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demonstrating the upper and lower limit valu s of the angle

gain $\alpha 11$. The reference value of the angle gain $\alpha 11$ is varied

depending on which vehicle, and with respect to general vehicles,

it may be about 1/15, for example. In this case, the upper

5 limit value of the angle gain $\alpha 11$ is set as 1/3, for example.

In the case of the angle gain $\alpha 11$ being 1/3, the angle gain

will be 5 times of the reference value thereof being 1/15.

Similarly, the lower limit value is set to be 1/75, for example.

In the case of the angle gain $\alpha 11$ being 1/75, the angle gain

10 will be 1/5 times of the reference value thereof being 1/15.

Further, FIG. 9 is a diagram demonstrating the upper and

lower limit values of the torque gain $\alpha 22$. As the torque gain

reference value, for example, used is 0.5 similarly to the first

embodiment. Setting 2.5 to the upper limit value thereof and

15 0.1 to the lower limit value thereof will make the sensitivity

of the steering torque 5 times and 1/5 times against the torque

gain reference value, respectively.

In the present embodiment, the angle gain $\alpha 11$ and the

torque gain $\alpha 22$ are each provided with the upper limit value

20 and the lower limit value. In this manner, even if any erroneous

signal input occurs due to a broken wire in the steering system,

sensor failure, and the like, the driver can control the vehicle

safely. Herein, the upper limit value and the lower limit value

are not necessarily set to both of the angle gain $\alpha 11$ and the

25 torque gain $\alpha 22$, and may be set either thereof.

Here, in the above embodiments, described is an example in which an electric power steering apparatus is applied to a steer-by-wire system. This is not restrictive, and the present invention can be widely applied to a system provided

5   with a motor for controlling the steering reaction force and a motor for controlling the actual wheel angle of tire, including a wheel angle superimpose system shown in FIG. 10. The wheel angle superimpose system shown in the figure is different from the steer-by-wire system in a respect that the tire 10 and the

10   steering wheel 20 are mechanically coupled to each other. In detail, a steering reaction force planetary gear 809 on the side of the steering wheel 10 and a wheel angle control planetary gear 810 on the side of the tire 20 are coupled to each other via a transfer shaft 811. Other components are similar to the

15   structure of FIG. 1, and thus not described again by providing the same reference numerals as those shown in FIG. 1. Here, the steering angle superimpose system is described in detail in the document authored by Kramer ("Potential Function and Benefits of Electronic Steering Assistance", CSAT, Czech

20   Republic, 1996).

According to the present invention, in an electric power steering apparatus including a steering system capable of flexibly setting the relationship between a steering angle of a steering wheel and a wheel angle of a tire, adjustment is

25   applied to a torque gain and an angle gain depending on the

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